Study of Electro Conductive Textiles: A Review

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ABSTRACT

Electro-textiles can be defined as textiles with unobtrusively built-in transporting electric current, electronic and photonic functions. Electrical functions can be embedded or incorporated in textiles by using weaving, knitting and embroidery or non-woven production techniques. The incorporation of electro conductive properties directly into the textile substrate carries some advantages such as increased comfort, mobility, usability and aesthetic properties. The effective incorporation of electric components on fibrous substrates constitutes an important research effort, aiming at the development of textile products with increased functionalities. However, this technology is purely interdisciplinary in nature, requiring basic scientific disciplines & technical expertise of electrical, electronic and textile technocrats. Hence there are some challenges to be addressed. This paper critically presents an overview of various aspects of conductive textile products, techniques, methodology and their potential for required functionality with a focus on three types of important applications including anti static , electromagnetic shielding and electro conductive three dimensional woven conductive fabric.

.***Keywords*** - *Conductive fiber, Conducting polymers, Electro conductive textile, Hybrid yarn, Woven conductive fabric*

1. INTRODUCTION

Clothing & textile have been exhibiting the changing culture and technology of its age. The function of clothing has shifted its trend from protecting human beings, in primitive age to its functionality in the modern era. Clothing of the future will be linked to complex composite structures and e- textiles Electrical functions of textile have been the focus of attention since last few years, The reason for the interest is the potential of textile material due to its structural order, ability to flex and conform to most desired shapes, hence offering a great opportunity to develop a new generation of multi functional textile materials. In recent years the dynamic potentials of e-textiles gained the attention of the research community, as an important source of emerging solutions in many application areas like electrical integrated circuits as sensors, electrical heating pads , wearable computing systems /interactive clothing – devices like health monitoring systems, mobile phones, mp3 players, computers integrated garments, electrostatic discharge , electromagnetic shielding etc. [1-5]

Many researchers have worked on the development of wearable electronic successfully achieved the electronic functionality, but compromises the fabric structure and aesthetics of the material Hence the effective incorporation of electric components on fibrous substrates is a challenging job requires an important research effort, aiming the development of electro textile products without affecting the wash ability, flexibility comfort as well as acceptable aesthetics.

Attempt of researchers is now focused on typical applications of conductive textiles includes anti static textiles, electromagnetic (EM) shielding, and e-textiles for flexible electronics. Conductive textiles can inhibit the static charge generated on fabric, to avoid uncomfortable feelings and electrical shocks. Conductive textiles can be used as shielding materials to shield EM radiation that is harmful to electronics and human. In the present era conductive textiles are becoming important building blocks to not only to design of wearable electronics, but it is now generating enormous scope for protective textiles for a broad range of applications. [5-9]

In this paper the fundamental principles of conductive textiles with a focus on three types of important applications including anti static, EM shielding, and electro conductive three dimensional conductive woven fabric is presented

2. CONCEPT OF CONDUCTIVITY IN TEXTILE MATERIAL

As a general principle of electrical engineering,when a voltage is applied from an energy source, an electric field is developed. This electric field forces the positively charged particles as well as the free electrons of the material to flow. The subsequent inability of the positively charged particles to move, results from their engagement into strong bonds.Electric current expresses the flow or the interaction of material's free electrons. Textile fibers behave typically as electric insulators. This is because of the absence of free electrons in the chemical structure of polymers. According to numerous studies conductivity in textiles can be introduced via: [1-8]

- ✓ Filling of fibers with carbon black or production of carbon fibers
- ✓ Interlacing in the textile structure metal , steel, or nickel wires or fibers
- ✓ Doping technique
- ✓ Coating of textiles (fibers or fabrics) with conductive substances
- ✓ Modification of the polymer structure through the effective incorporation in the textile structure of intrinsically conductive polymers (ICP)

3. ELECTRO CONDUCTIVE TEXTILES: TECHNIQUES & METHOD

Over the past decade, many techniques and materials have been used in order to produce electro conductive textiles. A brief overview of these materials and technique is discussed below:

3.1. Conductive Fibers

Naturally conductive fibers are generally developed from electrically conductive metals such as; ferrous alloys, nickel, stainless steel, titanium, aluminum, copper, and carbon. Metal fibers are very thin, metal filaments, with diameters ranging from 1 to 80 microns (pm). The conventional process to produce metal fibers is wire drawing, a mechanical production process. Drawing is the action of pulling a section of metal through a wear-resistant die, resulting in a reduction of cross-sectional area and an increase in length. Due to the die, the wires are perfectly round in cross-section with a smooth surface. A drawing apparatus often consists of a line of dies, each slightly smaller in diameter than the preceding one. A complete drawing apparatus may include up to twelve dies in a series sequence, each with diameter 20-30% smaller than the preceding one.[10],[11]In multiple-die machines, with an increase in length a corresponding increase in speed is required between each stage. The mechanical properties of the final wire depend on the chemical composition of the starting metal, the metal treatment and the final diameter reduction, or end-reduction. The metal wire work hardens during plastic deformation and the ductility is reduced while the tensile strength and hardness increases. To continue wire drawing to very small diameters, intermediate annealing is necessary to restore ductility.[12]

3.2. Conductive filler fibers

A conductive filler fiber can be manufactured by incorporating conductive fillers such as metallic powder, carbon black, carbon nanotubes, or conjugated polymers, to non-conductive polymers such as PP, PS, or PE. The homogeneous mixture of conductive fillers in polymers is done with great precautions before spinning process. Generally, the melt and solution spinning techniques is used to produce conductive filler fibers. The solution spinning process provides better electrical conductivity and mechanical properties, but due to requirement of large quantities of solvents, the costly and hazardous nature of some solvents, melt spinning is preferred over solution spinning process.[9], [13]

3.3. Treated Conductive Fibers

The conductivity in fiber, yarn or fabric can also be achieved by coating the fibers with metals, galvanic substances or metallic salts. Common textile coating processes include electroless plating, evaporative deposition, sputtering, coating the textile with a conductive polymer. The following treatments are in general practice.[9],[13]

3.3.1 Electroplating

In electroplating, metal particles are coated on to the textile material by means of electric current. It produces a thick, stiff and heavy coat of metals on textiles. In this technique generally metals like copper, gold, iron, nickel, silver , zinc, cadmium, chromium, etc. can be plated on fabric surfaces.The electroplating process is performed in an electro-cell which contains an electrolyte and two electrodes. Coating metal is anode, while the cathode is the part to be coated. Ions existed in electrolyte approach to the cathode and deposited to it. The metal coating on a textile substrate occurs due to chemical reaction between the reducing agent in the solution and the metal ions. Any substrate that remains stable in the electrolysis plating solution can be coated in this manner. [9]

3.3.2 Evaporative deposition

Evaporation is a common method of thin-film deposition. The source material is evaporated in a vacuum. The vacuum is an important component of this technique which allows vapor particles to travel directly to the target substrate, where they condense back to a solid state. Evaporation is used in micro fabrication, and to make macro scale products such as metalized plastic film. The fabric enters the vacuum chamber. The coating metal is then heated to a temperature just below the boiling point to allow the metal to substantially evaporate. The fabric is then, exposed to the vaporized metal where it condenses on the surface and changes to a solid forming the coating. Aluminum is commonly used in this coating process. This process can produce extremely thin coatings for lower levels of conductivity or relatively thick coatings when higher conductivity is required. It is one of the most commonly used processes.

It involves two stages: the evaporation of functional material and condensation. [9-13]

3.3.3 Sputtering process

The equipment consists of a vacuum chamber containing an inert gas, usually argon, at 10-3 to 10-1 torr. The chamber is equipped with a cathode (target), which is the source of the coating material, and an anode, which acts as a substrate holder. Application of an electrical potential of the order of 1000 VDC, between the two electrodes, produces a glow discharge. A flow of current occurs due to the movement of electrons from cathode to anode. The electrons ionize the argon gas. The argon ions are accelerated toward the cathode at a high speed due to the high electric potential. The bombardment of the energetic ion on the target results in a transfer of momentum. If the kinetic energy of the striking ion is higher than the binding energy of the surface atoms of the material of the target, atoms are dislodged or sputtered from its surface by a cascade of collisions. The sputtered atoms and ions condense on the substrate to form a thin film of coating. [9],[10],[13]

3.3.4 Coating with Polymers

Certain conducting polymers are not readily available as stable.The polymer can be chemically synthesized in the presence of a desired substrate to simultaneously effect polymerization and deposition, called as in situ solution polymerization. In this method, a substrate is placed into a solution containing the desired monomer and, if appropriate, other reagents, after which an oxidant is added to a solution to initiate polymerization. A certain fraction of the polymers formed in the reaction solution will passively adhere to the surface of the substrate. Depending the surface chemistry of the substrate and the presence/absence of reactive functional groups, reactive monomers or growing polymer chains can also become covalently attached to the substrate during the reaction.In situ solution polymerization is hard to control in real time. Ways to control mass transport during a polymerization/deposition are minimal and strategies to direct film growth kinetics are hard to enforce. The conjugated polymer coatings obtained via in situ solution polymerization display the highest degree of nonuniformity, surface roughness and batch-to-batch variation among all the fabrication methods summarized in this article. Small changes in reaction conditions (such as stirring/no stirring), monomer/oxidant concentrations and reagent addition order can lead to significant differences in film crystalinity/morphology, coating uniformity and correlated electronic properties. Moreover, some fabrics have been observed to degrade under the acidic reaction conditions necessary to effect pyrrole and aniline polymerization in solution. Therefore, this technique is best used with caution.[10-13]

3.4 Conductive Ink

Conductive ink is a modified form of traditional ink prepared by adding metals such as copper, silver, nickel and gold. When this ink it applied (printed) to a substrate, it conducts electricity. The commonly used substrates are paper, plastic and textiles. The printing techniques used are screen & inkjet printing. Both of these techniques are very simple to form conductive tracks either by means of direct printing on the textiles or printing an interface priming layer to make a smooth surface followed by printing over interface layer. However, the screen printing method is an inexpensive, flexible and fast way to obtain lightweight conductive coated textiles. [9],[25]

These conductive tracks can be used as interconnects in a printed circuit board and a fabric antenna or for bio-potential monitoring. Furthermore a dielectric and a conductive layer in various combinations, allows the formation of capacitors on textiles. Force sensing sensors are developed by means of printed resistors or piezoelectric materials. This form of printed resistors can also be used to produce a heater. Energy harvesting on fabric can be achieved by means of printed semiconductor layers based on thermo-electric harvesting and solar cells. Color variation in fabric can be achieved by printed chromic layers which change color in response to heat (thermo-chromic) or electrical stimulus (Electrochromic). [25] Conductive printing is very innovative and efficient technique for many application areas. However, there are certain practical problems associated with this technique, for example; some substrates like paper and plastic has high resistance and lack of rigidity. The nature of these materials creates undesirable forces, thus adversely affecting the performance of the component connections and causing reliability problems. Due to this such, materials are only used in a restricted range of applications.The conductive paints and inks crack and lose their conductivity on fabric because the surface of the fabric is porous and uneven. To print on stretch fabrics is an even bigger issue that might be resolved by combining the paints with flexible materials such polyurethane based elastomers containing silver flakes.

The electrical properties of conductive ink were not so good after washing. Some researchers have evaluated the electrical properties by measuring the square resistance of the printed textiles during different stages, such as after printing, abrading and washing. They put a protective layer on top of the conductive layers. Before and after washing the electrical properties of the samples were assessed. They found that the electro conductive textiles obtained from screen printing with both silver-based inks are washable. [26]

4. ANTISTATIC TEXTILES

Electrostatic discharges are caused when a sufficient amount of charge accumulated through different mechanisms (friction, induction or corona charging) is suddenly released on a nearby object. The magnitude of these discharges depends on a number of parameters, such as: air gap between the charged object and the one to which the discharge will be made, humidity, resistivity of the charged object, etc. Static electricity is the buildup of electric charge on the surface of objects, which can cause many problems for textile materials and fabrics in manufacturing and handling. In dry textile process, fibers and fabrics will tend to generate electrostatic charges from friction when they are moving at high speeds on different surfaces, such as conveyer belts,etc. causing fibers and yarns to repel each other. Static electricity can also produce electrical shocks, and the ignition of flammable substances. In general, two approaches are known to prevent static electricity in textiles: one is to create a conducting surface and the other is to produce a hydrophilic surface. The common practice is to use to produce conductive substrate by incorporating various techniques mentioned in preceeding section of this paper.

When human operators are met on the production line of devices sensitive to electrostatic discharge, a different protection measure is taken into consideration, namely ESD garments, which reduce the risk of an ESD from the operator's normal clothing to the sensitive device. The fabric, from which the garment is made, must fulfil at the same time two contradictory conditions: high resistivity, to limit the charging process and energy transfer in case of an eventual discharge, and high conductivity, to facilitate the dissipation process of charges, thus limiting the accumulation of charge on the fabric The protective garments must also have shielding properties, to prevent the electrostatic fields generated under the garment to induce charge to nearby objects and good anti-static properties, so that they won't generate electric charge when making contact with other materials . To satisfy the conditions for ESD garments (high resistivity and high conductivity), a bilayer structure of the fabric was developed. The bilayer structure offers both high resistivity and high conductivity, required for the ESD garments, while the integral knitting technique ensures the electrical conductivity throughout the fabric. [7],[14]

5. ELECTRO MAGNETIC SHIELDING TEXTILES

The wide spread use of electrical and electronic equipments devices in various industrial and house hold applications in form of automations, communications, computations etc., have capabilities to emit electromagnetic waves. The electromagnetic spectrum contains an array of electromagnetic waves increasing in frequency from extremely low frequency and very low to high frequency. Electromagnetic waves consists of an electrical and magnetic component are transverse waves that are composed of electric fields and magnetic fields perpendicular to each other and propagates at right angle to each other these waves are also called electromagnetic radiations.[15-17] These radiations led to electromagnetic interference (EMI) problems which create interruption, obstruction and overall degrade the effective performance of the circuit. The EMI has also an adverse consequence on human body by obstructing regeneration of cell and abnormal chemical activities to produce cancer cells.Electromagnetic shielding (EMS) is the process by which a material is capable to reduce the transmission of electromagnetic radiation that adversely affects the electronic equipments and human body.[17], [19-20] As per the basic shielding principle, when an object is exposed to the trajectory of an electromagnetic field, a part of radiation is reflected by the surface of the shield called reflection. A bit radiation, which actually passes through the barrier, is then attenuated in form of heat called absorption. The further penetration of radiation is reflected back and forth in the structure is called multiple reflections. There are various approaches for imparting protection against EMI such as metal materials, conductive polymers, metallic yarns and their hybrid derivatives with natural or synthetic fibers. Woven structures due to their ability to flex and conform to most desired shapes has been frequently opted for producing conductive fabric for EMS applications. [15-19]. Electromagnetic shielding is the process of reducing the electromagnetic field in a space by blocking the field with barriers made of conductive or magnetic materials by means of reflection from a conductive surface and absorption in a conductive volume. Conductive textiles owing to their flexibility, light weight and relatively low production costs are considered promising materials for the protection of equipment and people from electromagnetic radiation. The electromagnetic shielding expressed in decibel is mainly depends on reflection loss (S11) and transmission loss (S21) parameters. The transmission loss basically depends on reflection and absorption phenomena.[16],[21]

6. THREE DIMENSIONAL WOVEN CONDUCTIVE FABRIC

3D woven fabric due to their light weight, excellent shear strength, fracture toughness, damage tolerance has been the focus of attention of many researchers specifically for composite structures. The voluminous and multilayer structure has opened a new dimension of functionality in the form of electro conductive woven 3D structure . The multilayer composition of this structure has led to the development of interactive textile, woven switches, wearable antenna, sensors for smart fabric and electromagnetic shielding material with excellent absorption capabilities. The 3D resistive-type switch is based on the multilayer with conductive top and bottom layers separated by sand witched by insulating spacer n structure. Application of pressure makes the layers of conductive yarn to come in contact, which may be recorded using multi-meters. Removing the pressure cause the connection points to separate away. Such a switch can be used as an on/off switch for usage in security systems, can be sewn into carpets and wearable garments for a number of purposes .[23]

A micro strip antenna integrated into a 3D orthogonal woven fabric was successfully designed and fabricated by some researcher. The integration of the antenna and textile materials is very important in the army protective or data transmission clothing.. This type of antenna is designed to work in wearable or conformal antenna applications. Simulation work using HFSS software was made for the determination of antenna size. Antenna performance, including return loss, radiation pattern and gain were measured and the simulated results were found to have good agreement with the measured results. In one more study the effect of the weaving direction of conductive yarns on the electromagnetic performance of three-dimensional woven composite integrated with micro strip antenna (3DIMA) was reported. Designing, simulating and experimental testing of two microstrip antennas with different weaving directions of conductive yarns: one has the conductive yarns along the antenna feeding direction (3DIMAExp1) and the other has the conductive yarns perpendicular the antenna feeding direction (3DIMA-Exp2) was presented. The measured voltage standing wave ratio (VSWR) of 3DIMA-Exp1 was 1.4 at the resonant frequencies of 1.39 GHz; while that of 3DIMA-Exp2 was 1.2 at the resonant frequencies of 1.35 GHz. In addition, the measured radiation pattern of the 3DIMAExp1 has a smaller back lobe and higher gain value than those of the 3DIMA-Exp2. This result indicates that the direction of conductive yarns in woven 3D fabric may have a significant impact on the electromagnetic performance of textile structural antennas.[22],[24]

Study of the electromagnetic shielding effectiveness phenomenon of 3D conductive fabric using copper based hybrid yarn was attempted by some researchers. It was reported that the larger specific surface area of 3D configuration, has shown excellent electromagnetic shielding effectiveness. The impact of different structural configuration of fabrics on electromagnetic absorption behavior in both planes in C band (5.8-8.2 GHz) & X band (8.2-12.4) frequency range was also analyzed. It was found that the structural configuration in all 3D fabrics has also shown differential trends in terms of reflectance, transmittance and absorption behavior which signify that apart from a conductive material, structural attributes of the fabric has a significant role in achieving EMS effectiveness. [16],[21]

7. CONCLUSION

An overview of various aspects of conductive textile products, techniques, methodology and their potential for required functionality is critically analyzed. Applications and future scope of three important components ,including anti static, electromagnetic shielding and electro conductive three dimensional woven conductive fabrics was presented in this paper. The basic scientific principles of textile conduciveness also explained with a comprehensive fundamental understanding. The difficulty of the current study is routed in the interdisciplinary nature of e-textiles. Innovations in this area do not derive from structural textile modification textile modifications, rather than from a revolutionary re-appreciation of existing electronic technologies. In short, the challenge for device engineers in the near-term is to demonstrate that textile-based devices are truly ‘‘wearable,’’ meaning that they retain the feel, weight, breathability and pliability of standard fabrics.

A variety of coating methods were also analyzed; tremendous variation in the surface morphology of conjugated polymer-coated fibers can be observed with different coating or processing conditions. The morphology of the conjugated polymer active layer determines electrical and mechanical performance. It was found that conducting polymer coatings on traditional textile materials, including, vapor deposition, electrochemical deposition, in situ solution polymerization, etc. requires process control management, optimization of process and quality control guidelines.

Most of the textile and plastic materials are electrical insulators. They accumulate electrostatic charge, which causes problems such as severe shock, fire, dust accumulation, etc. during processing. The electrical conductivity is required to dissipate the charges and use of fibers blended with a conductive type of fibers prevents such risk. Hence there is an urgent need to develop various types of fibers and fabrics with electrical conducting properties.

In the present study a very limited approach for unobtrusive integration of electronics in constructing woven e---textiles was observed. In many cases the woven construction has not been fully utilized for the integration of electronics into the textile structure.

The voluminous and multilayer structure has opened a new dimension of functionality in the form of electro conductive woven 3D structure. The multilayer composition of this structure has led to the development of interactive textile, woven switches, wearable antenna, sensors for smart fabric and electromagnetic shielding material with excellent absorption capabilities. Study of the electromagnetic shielding effectiveness phenomenon of 3D conductive fabric using copper based hybrid yarn was attempted by some researchers. It was reported that the larger specific surface area of 3D configuration, has shown excellent electromagnetic shielding effectiveness specifically the absorption of electromagnetic waves. A further research in 3D conductive will not only provide construction of more complicated interactive textiles but will create a new scope for enhanced electromagnetic shielding capabilities.

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